

Abstract

This report presents the results of the study entitled "Economic Analysis of Wind-Powered Farmhouse and Farm Building Heating Systems", sponsored by the United States Department of Agriculture, Science and Education Administration, Agricultural Research, by Research Agreement No. 53-519B-9-15. Dr. Leo H. Soderholm, UDSEA, SEA, AR, NCR, was the ADODR for UDSEA. The study was performed by Regional Systems Services Group, Inc., Englewood, Colorado, R. Wayne Stafford, Program Manager.

The study evaluated the break-even values of wind energy for selected farmhouses and farm buildings focusing on the effects of thermal storage on the use of WECS production and value. Farmhouse structural models include three types derived from a national survey - an older, a more modern, and a passive solar structure. The eight farm building applications that were analyzed include: poultry-layers, poultry-brooding/layers, poultry-broilers, poultry-turkeys, swine-farrowing, swine-growing/finishing, dairy, and lambing. These farm buildings represent the spectrum of animal types, heating energy use, and major contributions to national agricultural economic values. All energy analyses were based on hour-by-hour computations which allowed for growth of animals, sensible and latent heat production, and ventilation requirements. Hourly or three-hourly weather data obtained from the National Climatic Center was used for the nine chosen analysis sites, located throughout the United States and corresponding to regional agricultural production centers.

Use of thermal storage was found to significantly enhance wind energy uses and its value for all applications. Thermal storage increased the break-even value of WECS energy for farmhouses by more than 50% - to over 4 cents/kwh for electric resistance and LP heating, to over 3 cents/kwh for fuel oil heating, and to over 2 cents/kwh for natural gas fuels. Use of thermal storage for farm building heating applications showed break-even values of energy falling between .8 and 6.3 cents/kwh for electricity, .8 and 4.6 cents/kwh for natural gas, .9 and 4.9 cents/kwh for LP gas, and .8 and 4.1 cents/kwh for fuel oil heating.

The study also evaluated the added value to the WECS production if the WECS output was also used for thermal storage for space heating and water heating, appliances and machinery, and sell-back to the local utility. State-by-state average wholesale electric rates for rural electric cooperatives were used as a basis for the value of WECS production sold to the local utility.

It is noted that for this study farmhouses were defined as any rural home reported by the 1970 Census of Housing, rather than assuming that one farmhouse would be associated with each farm operation reported by the Census of Agriculture. This definition of the farmhouses is believed to more completely represent the number of farmhouses located in rural areas which could accommodate the type of wind energy conversion systems (WECS) considered with this study.

This section presents a brief introduction and summary of the results of the investigations conducted under the Research Agreement Number 53-519B-9-15 entitled "Economic Analysis of Wind-Powered Farmhouse and Farm Building Heating Systems", sponsored by the United States Department of Agriculture, Science and Education Administration, Agricultural Research.

The ensuing paragraphs summarize the principal findings of this research and present an overview of the major study tasks and the approach defined for their investigation.

1.1 BACKGROUND

This study was initiated in August, 1979 by Regional Systems Services Group, Inc. of Englewood, Colorado to provide information about the economic break-even value of wind energy as it is applied to farmhouse and farm building heating systems, and in so doing, to define the analytical methodologies generally applicable.

Principal areas of research in this study have included:

- o A survey of farmhouses and farmbuildings to identify and quantify principal space heating requirements in agriculture using three characteristic farmhouse and eight farm building structures, located at nine geographically separate regions correlated to agricultural production centers.
- o An analytical determination of the annual energy flows for the selected farmhouse and farm building structures.
- o An examination of wind energy applications to the farmhouse and farm buildings to evaluate the needs that wind energy could satisfy considering:
 - The effects of wind variability on farmhouse and farm building energy requirements
 - An evaluation of wind energy to serve in a self-sufficient or supplemental mode.
 - The effects of non-uniformity in electric rates and other fuel costs on practicality and economic value.
- o An evaluation of life cycle wind energy break-even value goals considering present heating systems and energy sources used in agriculture.
- o A survey of present agricultural heating systems and heating costs.
- o An evaluation of the number of potential wind energy uses correlated to agricultural energy sources and life cycle break-even cost goals for wind energy applications.

The analysis has proceeded with the recognition that building heating consumes approximately 10% of the energy used in agriculture, and more than 90% of the heating energy is used in the farmhouse. Subsequent sections summarize the principal conclusions and the results of the research.

1.2 PRIMARY CONCLUSIONS

The principal conclusions suggested by this research are presented in the following paragraphs:

o Thermal storage, even in small amounts, significantly improves the ability to utilize WECS production for space heating.

This conclusion is illustrated in Figures E-1 and E-2 which show the percentage of WECS production usable with and without the inclusion of thermal storage for farmhouses and farmbuildings, respectively. The results are separated by warmer and colder climates for the farmhouses, and are specific for the sites used for the farmbuildings. A WECS with a 20 foot diameter rotor and a 10 KW generator is used for the illustration. The thermal storage used for the farmhouses was 600 gallons for a preheat tank and a normal 100 gallon hot water heater. Thermal storage for the farmbuildings was sized for the specific application and is discussed in the main body of the report.

The increased use of the WECS production is most dramatic in the warmer climates where the space heating requirements are lower. Even in colder climates the use of thermal storage nearly doubled the use of WECS energy. All of the analyses were based on hour by hour evaluation of the time coincidence of the production from the WECS and the farmhouse and farmbuilding energy needs.

o Wind-powered heating systems, over long periods, can displace significant proportions of primary heating fuels.

With thermal storage, the heating fuel displacement increases greatly, nearly doubling in most cases. This result is further illustrated in Figures E-3 and E-4 which show the percentage of heating energy which was displaced in the farmhouse and farm building applications, respectively. The results shown also use a WECS of 20 foot rotor diameter with a 10 KW generator. For the older and modern farmhouse models used with the study, thermal storage with the WECS allowed the displacement of nearly 2/3 of the heating energy in a warmer climate and approximately 1/3 of the heating energy in the colder climates. Using a WECS in combination with a passive solar farmhouse allowed the displacement of nearly 90% of the heating energy needs in cooler climates, and nearly all of the heating energy in a warmer climate.

For farmbuildings with thermal storage, nearly 1/3 of heating needs were provided by the 20 foot diameter WECS for the dairy and turkey application. 13% to 16% of heating was provided for brooding/layers, swine-farrowing, and swine growing and finishing. Less than 10% of the farm building heating needs were met elsewhere due to the warm climate

20 FOOT DIAMETER WECS

10 KW GENERATOR

NS: NO THERMAL STORAGE S: THERMAL STORAGE

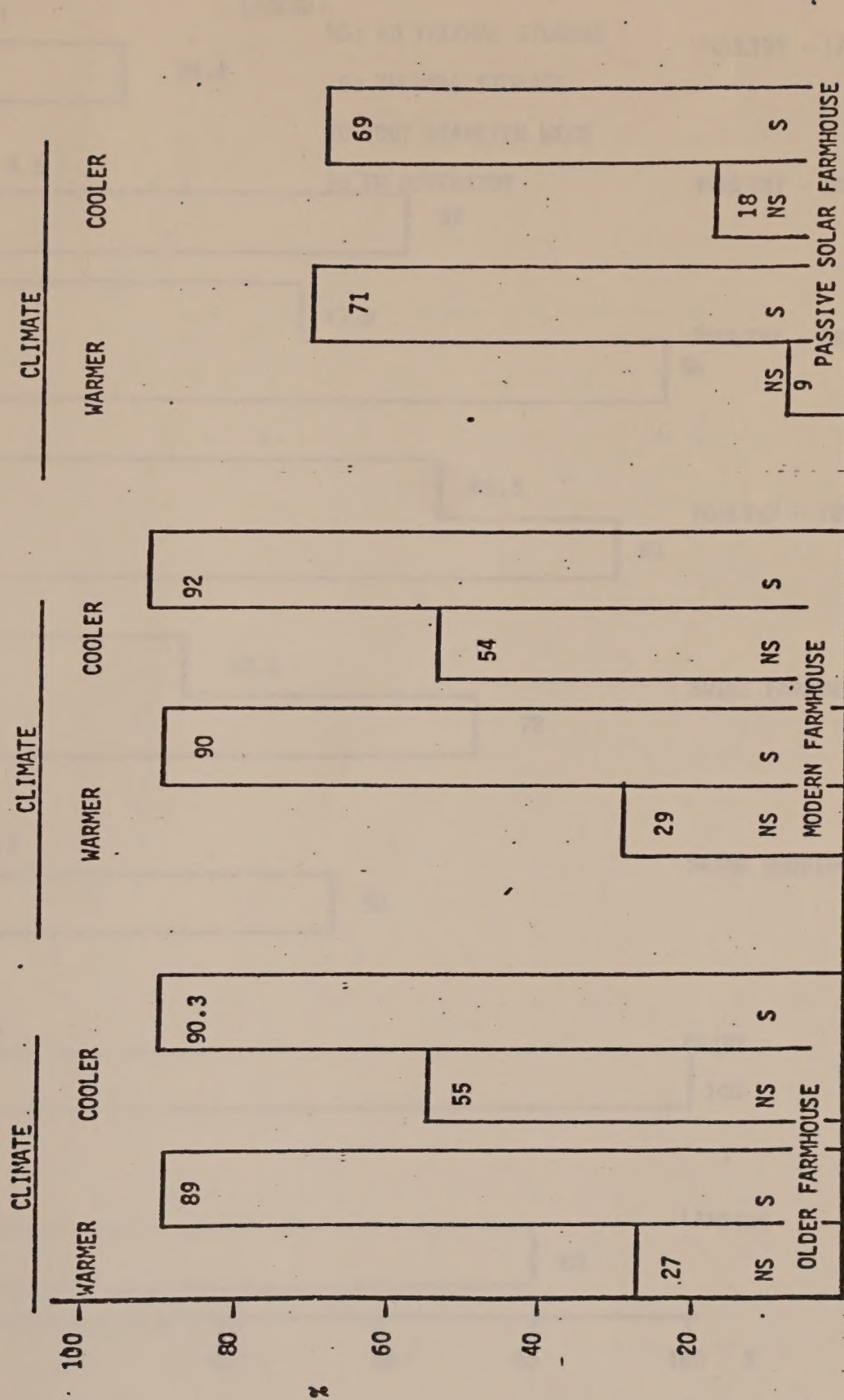


Figure E-1 Effect Of Thermal Storage On The Percentage Of WECS Production Usable For Heating In Farmhouses

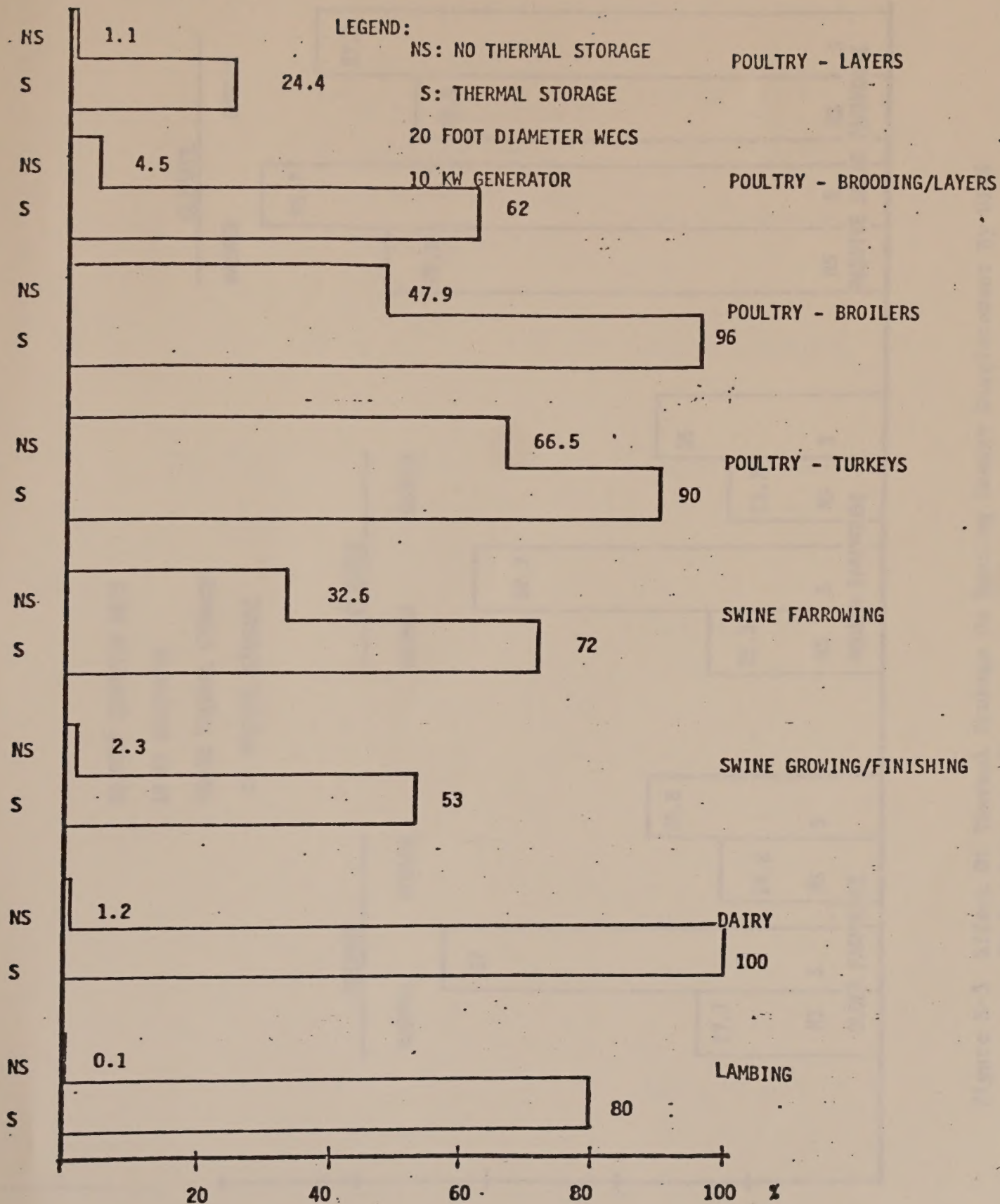


Figure E-2 Effect Of Thermal Storage On The Percentage Of WECS Production Usable For Heating In Farmbuildings

20 FOOT DIAMETER WECS

10 KW GENERATOR

NS: NO THERMAL STORAGE

S: THERMAL STORAGE

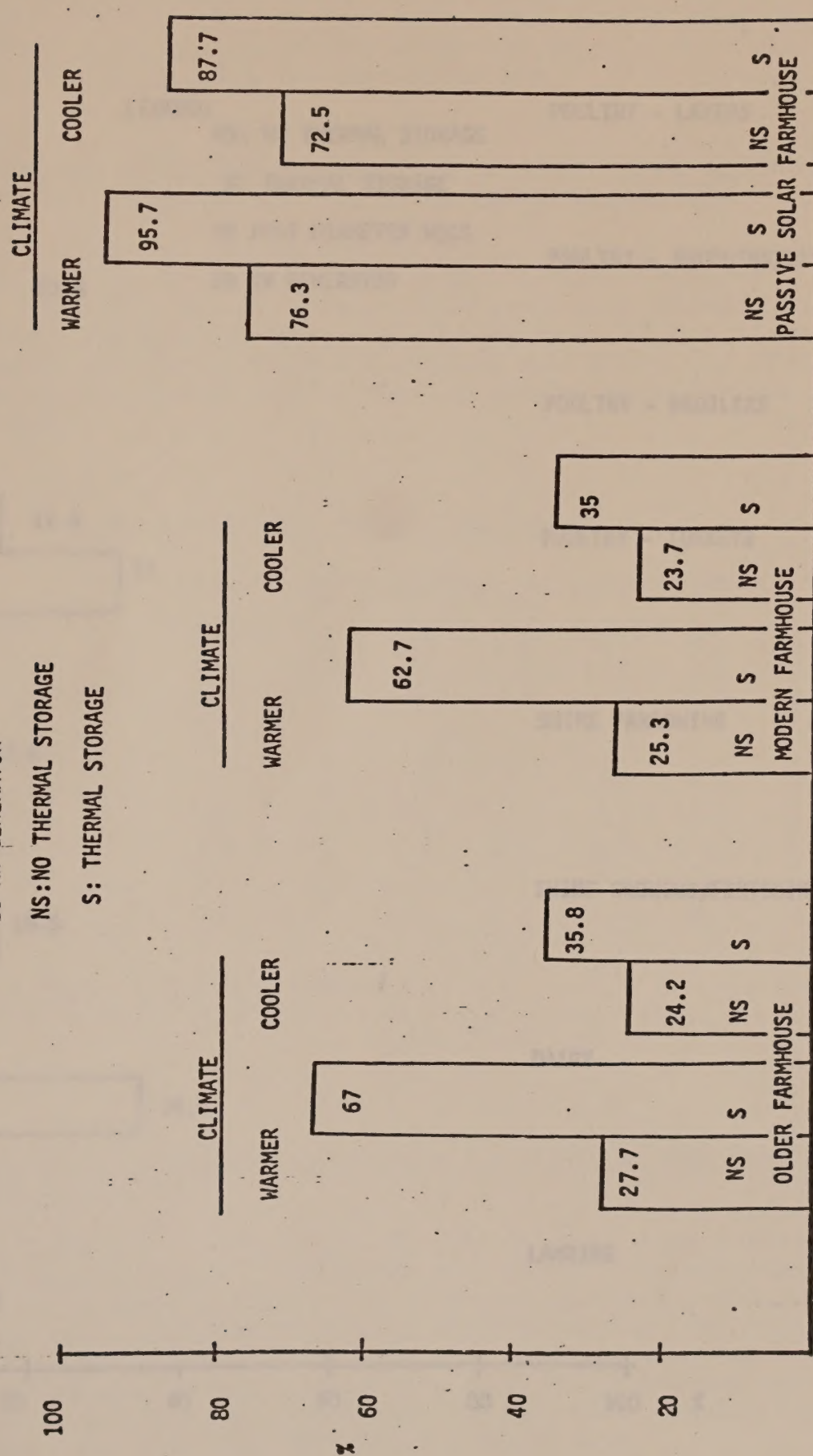


Figure E-3 Effect Of Thermal Storage On Heating Energy Displacement By WECS In Farmhouses - %

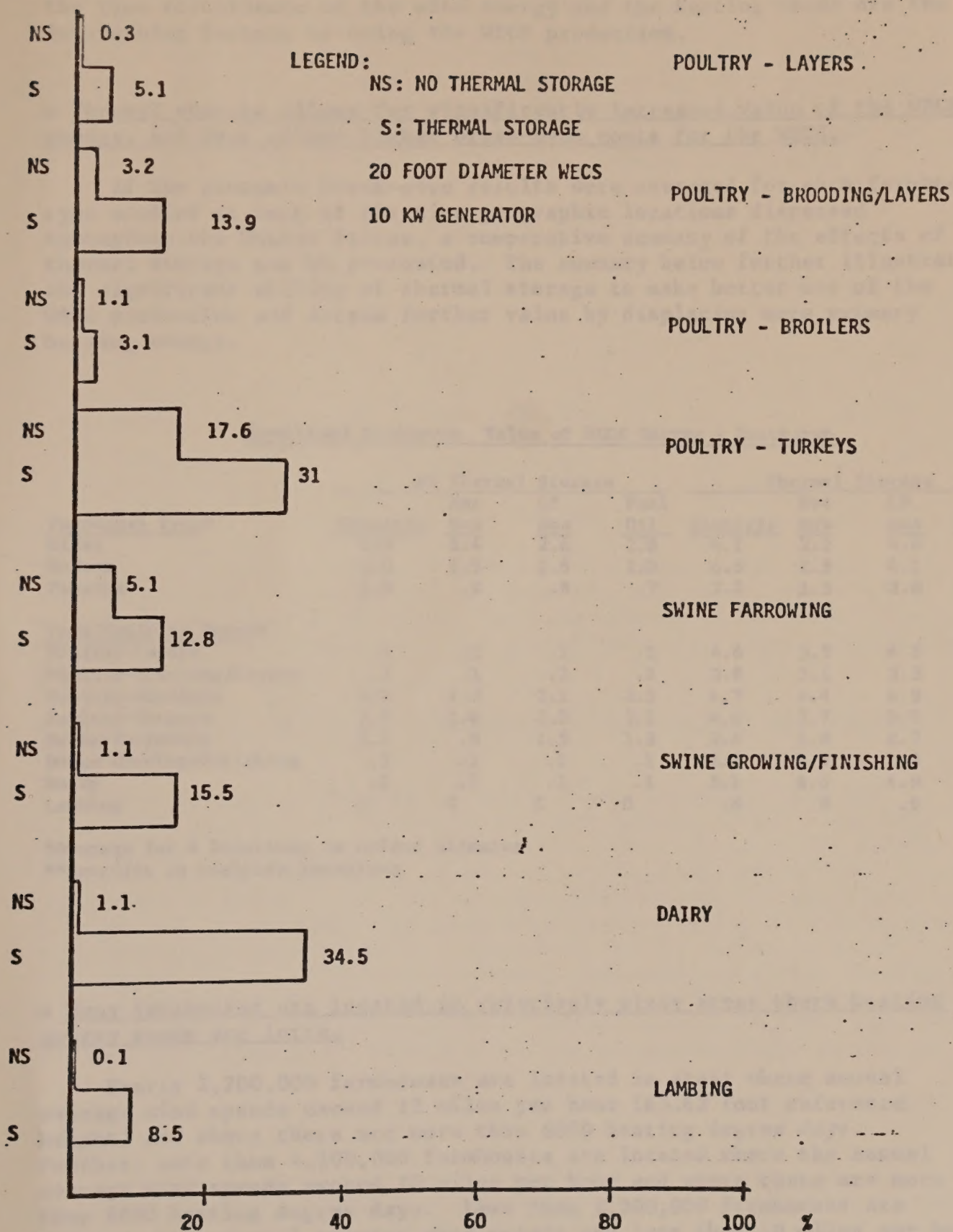


Figure E-4 Effect Of Thermal Storage On Heating Energy Displacement By WECS In Farmbuildings - %

or small need for space heating energy.

Simply increasing the size of the WECS does not necessarily displace more of the heating energy needs, since as this study showed, the time coincidence of the wind energy and the heating needs are the determining factors in using the WECS production.

o Thermal storage allows for significantly increased value of the WECS energy, and thus allows higher break-even costs for the WECS.

If the economic break-even results were averaged for each farmhouse type studied at each of the nine geographic locations dispersed throughout the United States, a comparative summary of the effects of thermal storage can be presented. The summary below further illustrates the significant ability of thermal storage to make better use of the WECS production and accrue further value by displacing more primary heating energy.

Levelized Breakeven Value of WECS Energy - Cents/kwh

Farmhouse Type*	No Thermal Storage				Thermal Storage			
	Electric	Nat Gas	LP Gas	Fuel Oil	Electric	Nat Gas	LP Gas	Fuel Oil
Older	2.9	1.4	2.6	2.0	4.1	2.2	4.0	3.2
Modern	3.0	1.5	2.6	2.0	4.5	2.5	4.1	3.1
Passive	1.0	.9	.9	.7	2.2	1.3	2.0	1.7
<u>Farm Building Type**</u>								
Poultry-Layers	.2	.1	.1	.1	4.6	3.9	4.2	4.1
Poultry-Brooding/Layers	.3	.1	.2	.2	3.8	3.1	3.3	3.2
Poultry-Broilers	3.3	2.2	2.1	2.5	6.3	4.4	4.9	4.1
Poultry-Turkeys	3.0	1.6	2.5	2.1	4.6	2.7	3.8	3.2
Swine-Farrowing	2.1	.9	1.5	1.3	3.4	1.8	2.7	2.3
Swine-Growing/Finishing	.3	.1	.1	.1	2.2	1.2	1.8	1.6
Dairy	.1	.1	.1	.1	5.1	4.6	4.9	4.7
Lambing	0	0	0	0	.8	.8	.9	.8

*Average for 6 locations in colder climates

**Specific to analysis locations

o Many farmhouses are located in relatively windy areas where heating energy needs are large.

Nearly 2,200,000 farmhouses are located in areas where annual average wind speeds exceed 12 miles per hour (65.62 foot reference height) and where there are more than 6000 heating degree days. Further, more than 4,100,000 farmhouses are located where the annual average wind speeds exceed 10 miles per hour and where there are more than 6000 heating degree days. Less than 2,200,000 farmhouses are located where annual average wind speeds are less than 10 miles per hour and where there are less than 2000 heating degree days.

o The design ratings of farmhouse heating systems are closely correlated to the annual average wind speeds.

The required peak ratings for the heating systems, defined using methods recommended by ASHRAE, were found to be directly related to the annual average wind speeds in the area of the farmhouse. For example, the peak ratings in areas where the annual average wind speeds exceeded 12 miles per hour were nearly double the heating system peak ratings where the annual average wind speeds were less than 10 miles per hour (65.62 foot reference height). The brief summary below further illustrates this conclusion.

Average Annual Wind Speed, miles per hour (65.62 foot reference) Equivalent	Farmhouse Heating System Peak Rating BTU/hour	Kwh/hour
< 10	55,000 - 78,000	15 - 23
10 - 12	62,500 - 99,000	18 - 29
> 12	67,500 - 112,000	19 - 33

With the wide range of heating system peak ratings in the higher wind regimes, greater flexibility of matching the WECS output power to the present energy needs will exist. Both the minimum and maximum ratings shown in the above summary are seen to increase with annual average wind speed.

o Heating system peak sizes also increase directly with the heating degree days.

Although some variations in local solar insolation, wind and temperature conditions were noted, the peak heating system sizes were closely correlated with the heating degree days. Based on the thermal envelopes for the farmhouses selected for this study, the older farmhouse, in spite of its smaller size (1067 square feet of living area), would require about the same peak furnace rating as a more modern farmhouse (1650 square feet of living area) if the rating is based on both conduction and infiltration loads. The levelized annual heating costs of the two houses is nearly equal. This result clearly shows the effect of improved insulation, double pane windows throughout, and the improved use of building materials for the more modern type farmhouse.

o The levelized annual heating cost increases with the annual average wind speed.

Combining the state by state energy costs (reported by the Department of Energy) with wind speeds and heating energy found in this study, the range of levelized annual heating costs for the older and modern farmhouses is compared below.

Levelized Annual Heating Costs in Dollars *

Heating Fuel	Wind Regime **								
	Low			Medium			High		
	Less Than 10 MPH			10 to 12 MPH			Greater Than 12 MPH		
	Low Dollar Amount	Median Dollar Amount	High Dollar Amount	Low Dollar Amount	Median Dollar Amount	High Dollar Amount	Low Dollar Amount	Median Dollar Amount	High Dollar Amount
Electric-Resistance	500	1000	1500	1400	2200	3200	900	1400	3600
Electric-Heat Pump	250	500	750	700	1100	1600	500	700	1800
Natural Gas	400	600	1100	700	1200	2500	620	1100	2900
LP Gas	400	930	1735	1100	1800	2400	750	1300	3600
Fuel Oil	270	420	1400	1200	1600	1900	1400	1700	2600
All Fuels	330	930	1700	700	1530	3550	600	1700	3600

* Levelized with a 25 year life and 10 % discount rate

** Wind speeds referenced to 63.62 feet (20 meters)

Considering the aggregate of all fuels and all winds, the median levelized annual heating costs fall between \$930 and \$1700. The median cost for LP is generally greater than for electric resistance heating. The electric heat pump showed potential for lower median heating costs than all other fuels, and was competitive with natural gas and fuel oil even in low wind regimes.

o The combined use of WECS production for more than just space heating significantly increases the value of the WECS energy and greatly increases the potential numbers of economically viable applications.

If, in addition to its use for spaceheating and thermal storage for spaceheating, the WECS output was applied to hot water, appliances, and machinery before selling the surplus back to the local utility, the break-even value of the WECS energy more than doubles for electric heating, and nearly triples for petroleum based heating fuels. This result is further illustrated in Figure E-5 which shows the potential number of farmhouses which had levelized heating energy costs equal to or greater than the break-even value of the WECS production found with this study. The break-even values of the WECS production are shown for five different strategies for the use of WECS production, beginning with space heating only.

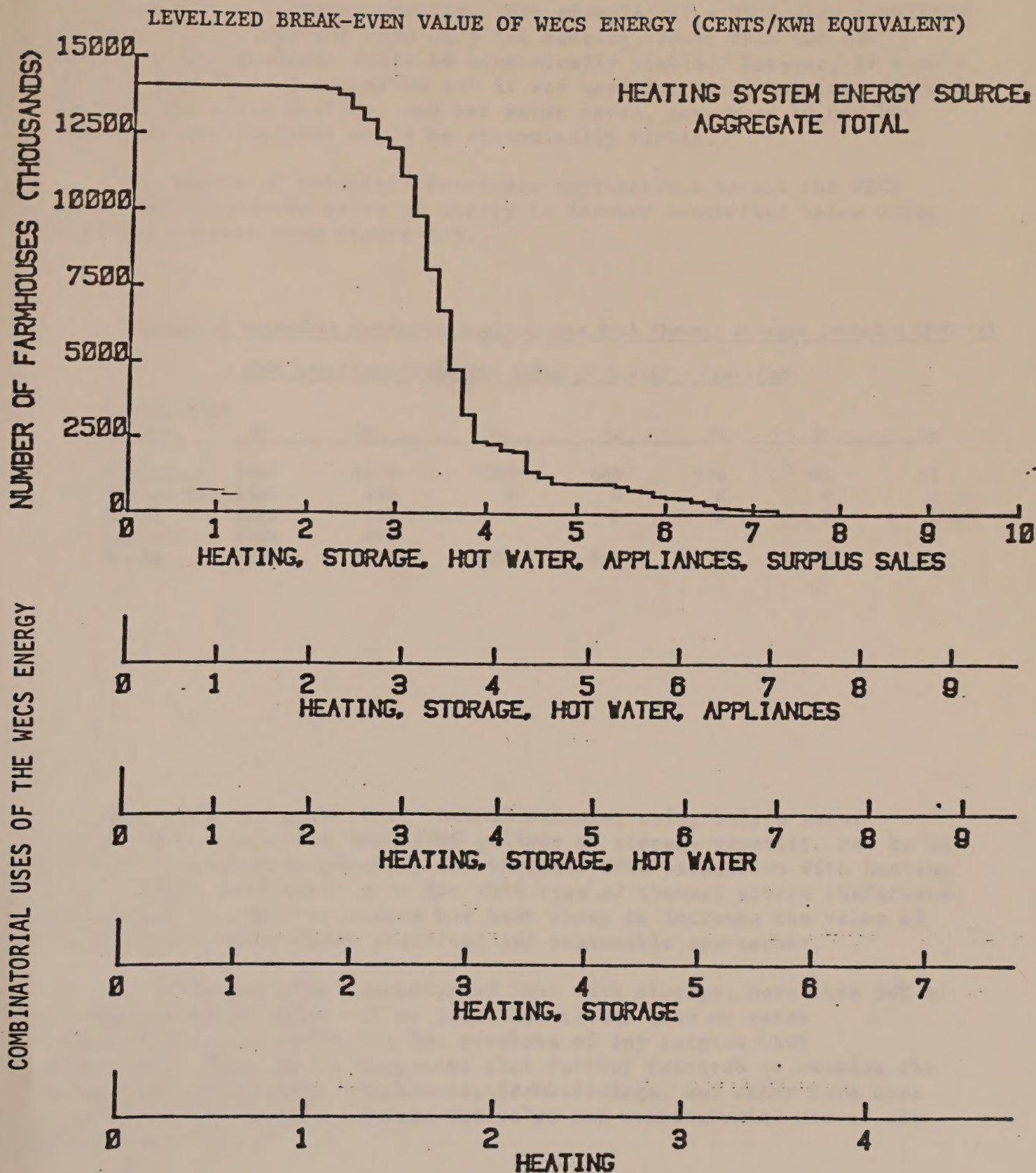


Figure E-5 Effect Of Combinatorial Uses Of WECS Production On Break-even Value And Number Of Economically Viable Applications For Farmhouses Using All Types Of Fuel Examined For Heating

The result shows that the combinatorial use of the WECS production greatly increases its value and allows the economically viable applications to increase greatly. For example, if a WECS were available costing 3 cents/kwh and used only for heating, fewer than 500,000 farmhouse applications would be economically viable. However, if a WECS were available at 3 cents/kwh and it was used for space heating, thermal storage for space heating, and hot water needs, more than 10,000,000 farmhouse applications would be economically viable.

The number of potential farmhouse applications versus the WECS levelized break-even value of energy is further summarized below using specific results from Figure E-5.

Number of Potential Farmhouse Applications With Thermal Storage Included (1000's)

Heating Fuel Type	<u>WECS Levelized Breakeven Value of Energy - Cents/kwh</u>						
	3c	4c	5c	6c	7c	8c	9c
Electricity	1364	1079	1005	608	176	63	42
Natural Gas	2595	289	0	0	0	0	0
LP Gas	2863	132	5	0	0	0	0
Fuel Oil	5285	899					
Totals	12107	2399	1010	608	176	63	42

The study has shown that thermal storage, using only a water storage medium and less than 1000 gallons of storage capacity, can be an effective approach to matching the variable WECS production with heating loads. Since projected costs for this type of thermal storage (Reference 51) are modest, this technique has been shown to increase the value of the WECS production using practical and reasonable approaches.

The study has also demonstrated that with storage, more than 90% of the WECS value is dependent on local use rather than on rates established by the utilities for purchase of any surplus WECS production. Thus, it is suggested that further research to examine the matching of loads among farmhouses, farmbuildings, and other farm uses be conducted to further measure the value and combinatorial use of the WECS production.

